Multidisciplinary Redesign of Hill Air Force Base Modular Storage Magazine for Orote Point, Guam
2010 DDESB Seminar

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Abstract

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The final MSM is an earth-covered, reinforced concrete box with a single sliding door. NAVFAC Pacific was responsible for overall design and satisfying user requirements. NAVFAC ESC was responsible for explosives safety and physical security requirements. The final design addresses several outstanding issues. Structural analysis was conducted to meet seismic criteria for the Guam region. The magazine roof, sidewalls, front headwall, and door have been modified to meet the required explosive safety standards. The change from a double swinging door to a single sliding door satisfies physical security and logistics requirements. The change will enhance ordnance handling operations. Physical security requirements were considered upfront by integrating access delay technologies and advance locking systems into the door and headwall. This paper summarizes the critical design details and advanced analysis methods used to guide and validate the design changes; including finite element, Single Degree of Freedom analysis and parameter studies.

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14. ABSTRACT
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1.0 INTRODUCTION

1.1 BACKGROUND

Naval Region Marianas has operational requirements to justify construction of new earth-covered magazines (ECMs) at Orote Point, Guam. The Naval Facilities Engineering Command (NAVFAC) Pacific is responsible for the planning, design and construction of ordnance facilities. NAVFAC Pacific awarded design contract N62742-08-D-001 for the design of ECMs at Orote Point, Guam. The contract was awarded to Wilson Okamoto Corporation to design the 14-foot tall Guam MSM, ensuring; (1) compliance with design codes for conventional loads, including seismic, and (2) satisfy operational requirements for stowing and retrieving ordnance from the magazine.

The contract requires design of a series of Guam Modular Storage Magazines (MSMs) which are based on the Hill Air Force Base (AFB) MSMs. The Hill AFB MSM is a box-shaped, earth covered magazine (ECM) that is constructed from pre-cast concrete panels. The Hill AFB MSM is listed as a 7-Bar ECM approved for new construction in Table AP 1-1 of Department of Defense Explosive Safety Board (DDESB) Technical Paper 15 (Ref 1).

NAVFAC Pacific tasked the Naval Facilities Engineering Service (NAVFAC ESC) to review the Guam MSM design drawings to ensure compliance with Department of Defense (DoD) and U.S. Navy explosives safety standards (Ref 2 & 3). The final design of the Guam MSM was submitted to the Department of Defense Explosives Safety Board (DDESB) for review and approval for new construction as a 7-Bar ECM (Ref 4). NAVFAC ESC produced the 2009 Site Specific Report SSR-3437-SHR (Ref 5) detailing the design changes and analyses. This paper summarizes that report.

1.2 DESIGN ISSUES

During the design of the new MSMs for Orote Point, four design issues were identified that required modifications to the original Hill AFB MSM. The four issues included (1) satisfying seismic design criteria in regions of high seismicity, (2) eliminating safety issues during stowing and retrieving ordnance from the MSM, (3) satisfying physical security protection criteria, and (4) ensuring the structural modifications satisfied explosives safety standards.

In 2007, a series of MSMs were built at Andersen AFB (Figure 1). The design of this magazine was based on Modified STD 421-80-06 (Ref 6). During the design of the Andersen AFB MSM, Dick Pacific Construction informed NAVFAC Pacific that the cross-section of the roof panels did not satisfy ACI-318 (Ref. 7) design requirements.


Figure 1 An MSM under construction.

In response to horizontal ground acceleration during an earthquake, the Modified STD 421-80-06 roof must behave as a horizontal diaphragm. A review of the Modified STD 421-80-06 design drawings, determined that they did not satisfy current criteria in ACI 318-05 and FEMA 450 (Ref. 8) to resist seismic loads. The critical structural components that do not satisfy seismic design criteria include: (1) the connections between the pre-cast, concrete roof panels, (2) the connections between the roof panels and the wall panels, and (3) the connections between the wall panels and the foundation.

For connections between roof and wall panels, ACI 318-05 and FEMA 450 prohibit the use of mechanical connections between pre-cast panels unless analysis and empirical data show sufficient strength and toughness to resist the design loads. Without empirical data, ACI 318-02 and FEMA 450 require a topping slab to be placed over the pre-cast concrete panels to act as the structural diaphragm. This was the solution for the Andersen AFB MSM and the DDESB reviewed the final design drawings and classified the magazine as approved for new construction and use as a 7-Bar magazine.

The Hill AFB MSM design (Ref. 12) is also based on Modified STD 421-80-06 and does not comply with ACI-318 and FEMA design requirements. Therefore, NAVAFC Pacific determined the original Hill AFB roof required a topping slab to satisfy seismic design code by ensuring the magazine roof acted as a structural diaphragm.

Hill AFB MSM has a right-hand and left-hand double swinging magazine blast door. To resist the design blast loads, each assembly is supported along the top, bottom and hinged edges. To provide the support along the bottom edge an 8 by 8-inch steel tube is embedded in the magazine floor as shown in Figure 2. The elevation difference between the top of the steel and the concrete can be as much as 4-inches. Although portable ramps, seen in Figure 3, are used to allow weight handling equipment access to the magazine this configuration is a safety issue.

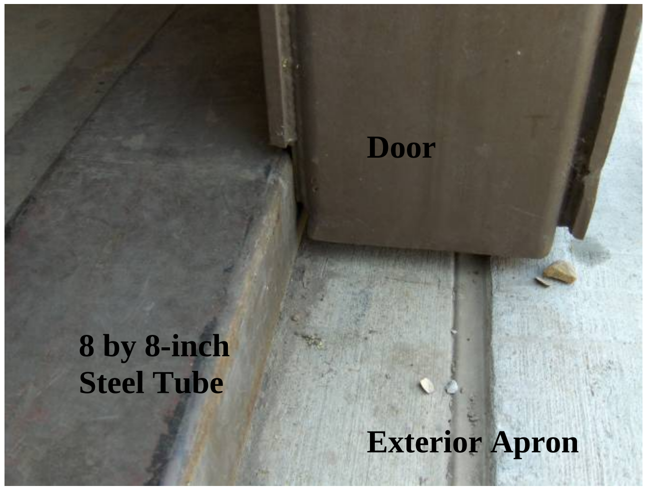

Figure 2 Steel tube and closed door at door threshold.

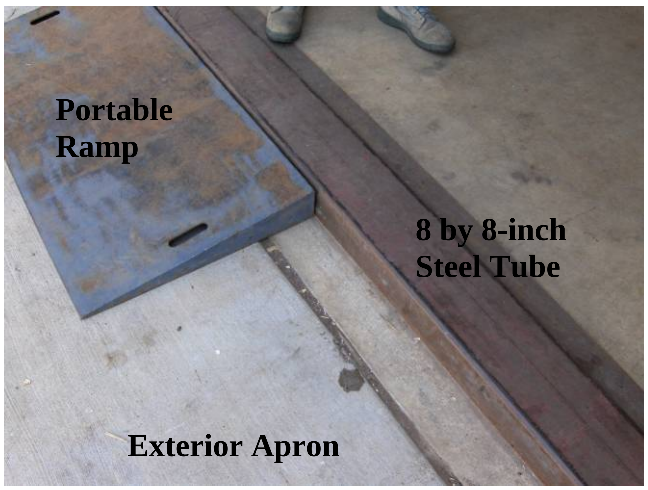

Figure 3 Door threshold with portable ramp.

MIL-HDBK 1013/1A sates that hinges to doors for Arms, Ammunition and Explosives (AA&E) magazines are vulnerable to physical attack. Attacks on door hinges may consist of cutting the hinge assembly. To resist physical security attacks on the door hinges, a positive interlock between the door and the supporting frame is required. To resolve both the physical security and ordnance handling equipment safety issues, a sliding door was designed to replace the double swing door.

The changes to the MSM roof and door design represent significant structural changes to the Hill AFB MSM design. The DDESB has issued a memorandum defining the minimum requirements to validate facilities and prevent propagation of explosions (Ref. 9). Reference 9 states that a DoD component must provide supporting experimental test reports and blast analyses to validate the level of protection provide by the facility design. The Modified STD 421-80-06 design was validated by a series of explosives tests (Refs. 10 and 11). The Hill AFB door design was validated by blast calculations according to criteria in Reference 2. NAVFAC ESC analyzed the modifications of the Guam MSM using criteria in Reference 2 and conducting additional analyses using finite elements software.

1.3 SCOPE

NAVFAC ESC assisted in the redesign and reviewed the final design drawings of the 14-foot tall Guam MSM. Specifically the NAVFAC ESC scope of work was:

1. Reviewing critical sections and details of the structural elements of the 14-foot tall Guam MSM final design.
2. Demonstrating that the redesigned magazine door design provides the required protection from 7-Bar blast loads.
3. Demonstrating that the magazine side wall design meets requirements.
4. Demonstrating that the magazine roof provides the required protection from 7-bar blast loads.

NAVFAC Pacific has reviewed the final design drawings and design calculations and has responsibility for the following:

1. Reviewing critical sections and details of the structural elements of the 14-foot tall Guam MSM final design
2. Demonstrating that the 14-foot tall Guam MSM satisfies the explosives safety standards for grounding and lightening protection
3. Demonstrating that the magazine design satisfies design codes for conventional loads, including live, dead, and seismic loads

1.4 DESIGN CONSIDERATIONS

The modern Arms, Ammunition and Explosives (AA&E) storage facility is a complicated environment with many competing requirements. Primarily, a magazine must meet the strict conventional and explosive safety structural requirements. There are also access control and physical security policies to satisfy. Users of the magazine have also been providing feedback about how the configuration of the doors and ramps affect their ability to quickly and safely store or retrieve assets without incident.

As such, the NAVFAC Pacific and NAVFAC ESC team decided to incorporate these key planning factors into the final design of the Guam MSM:

1. Conventional structural design loads, including seismic and building codes
2. Explosives safety requirements to prevent propagation of detonation between ECMs.
3. Ordnance handling procedures define requirements to mitigate safety issues during stowing and retrieving of ordnance from the magazine.
4. Current and new physical security requirements to define the level of protection to mitigate unauthorized access to stored assets.

2.0 DOOR ANALYSIS

2.1 DOOR MODIFICATION

As stated in Section 1.2, a sliding door was designed for the Guam MSM to mitigate ordnance handling equipment safety issues and to increase the physical security protection against unauthorized access. The final door design is designed to resist the design blast loads defined in Paragraph C5.2.1.2.4.2 of DOD 6055.09-STD (Ref. 3). The design blast load for the door of a 7-Bar earth-covered magazine (ECM) is triangular pulse with a peak pressure of 101.5 lb/in^2 and

an impulse of $13.9W^{1/3}$ lb/in^2-ms. For a maximum credible event (MCE) of 500,000 lbs of net explosive weight (NEW), the deign blast load is defined by a peak pressure of 101.5 lb/in^2 and an impulse of 1,103 lb/in^2-ms and a duration of 21.74 ms.

2.2 NEW DESIGN

Details of the new sliding magazine door are found on drawings Sheets S-701 through S-708 of the final Guam MSM drawings (Ref 4) and are reproduced in Figure 1 and 2. The magazine door is a single sliding nominally 26-feet (7924-mm) wide by 15-feet 8-inches (4775-mm) tall. The door frame opening is 25-feet (7620-mm) wide by 14-feet 8-inches (4470-mm) tall. There is a 6-inch (152-mm) overlap between the door and the doorframe on all sides. The door cross-section (Figure 4 and Figure 5) consists of ⅜-inch (9.5-mm) thick front and back plates that are welded to the internal stiffeners. The internal stiffeners are ⅜-inch (9.5-mm) by 8-inch (203-mm) plates. The stiffeners run horizontally and vertically, 12-inch (305-mm) center-to-center in both directions, and are welded to the back plate. L3x3x⅜ angles are fillet welded to the stiffeners along three edges, and then to the front plate. The door is supported on four edges to resist the design blast loads. C8x18.75 channels run along the all edges. Because of physical security requirements the design includes lightweight concrete cast over rebar at the rear 2-inches (51-mm) of the door.

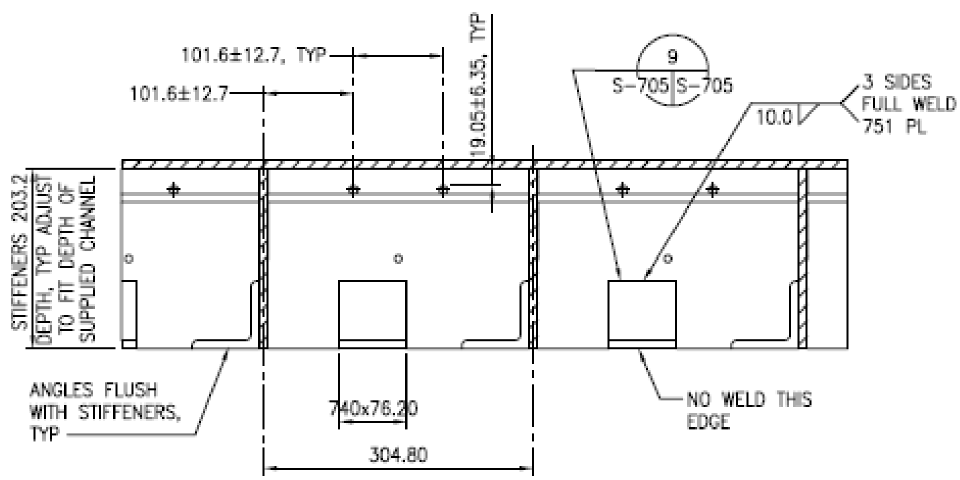

Figure 4 Cross-section of door shown without front plate or concrete.

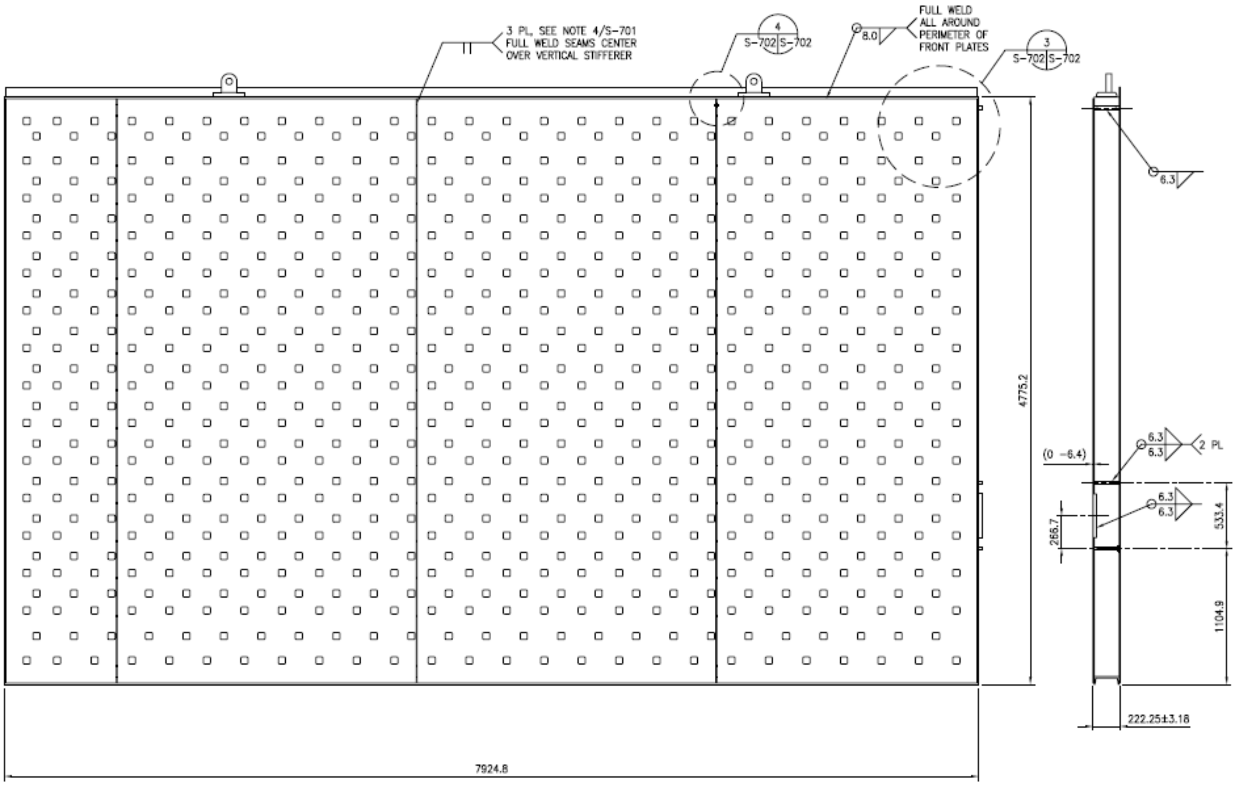

Figure 5 Final Door design elevation view.

The door sits in a trench and moves horizontally via an overhead electric trolley mechanism. There is also a manual chain back up. When closed the right edge of the door is captivated by a pilaster where the locking mechanism is located as seen in Figure 6. To span the gap of the trench when the door is open, trench plates fold forward resting flush with the floor slab. The plates have been sized for expected wheel loads of the weight handling equipment. This configuration allows the entire 25-foot span and 14-feet 8 inch height of the magazine opening to be accessed without obstacles.

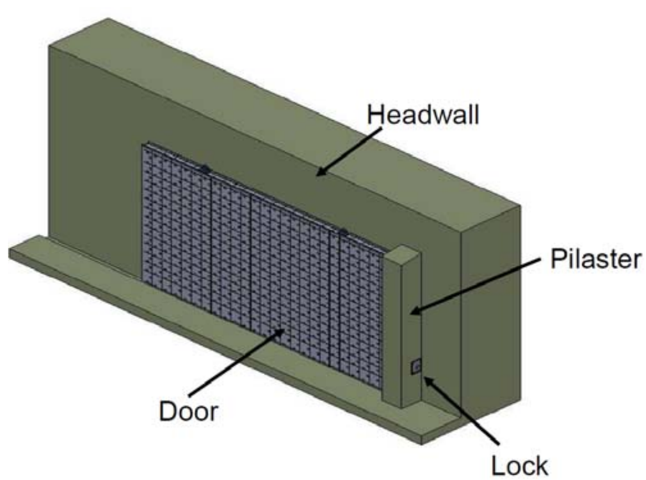

Figure 6 Solid Model front view of the Guam MSM

2.3 ANALYSIS

The door was analyzed as a two-way element, simply supported on four edges using the Single Degree of Freedom (SDOF) method found in UFC 3-340-02 (Ref. 2). It was found that the shear capacity of the door cross-section is sufficient to take the blast load and the support rotation and ductility are within prescribed limits. The results of this analysis also showed that the shear capacities of all welds are sufficient to carry the shear loads. A summary of the results is presented in Table 1 and Table 2.

According to Reference 2, steel blast doors can have a maximum support rotation of 12 degrees with a ductility of 20 (sections 5-16.7 and 5-36.3.2 of Ref 13). As presented in Table 1, the deflection and support rotation are within those limits. Shear capacity of the door was also checked and is greater than the shear load, thus the web provides sufficient area to survive the blast load.

Table 1 Deflection and Support Rotation Summary

Ductility μ	Maximum Deflection X_m [in]	Support Rotation θ [degrees]
2.226	3.342	2.175

In addition to verifying the sufficiency of the door to carry shear loads, it is equally important to verify that the welds can withstand the applied loading conditions. There are three types of welds used in the design of the door: ¼-inch (6.4-mm) fillet welds connecting the web (internal stiffeners) and the front plate, ⅜-inch (9.5-mm) fillet welds connecting the angle and the web, and ⅜-inch (9.5-mm) fillet welds connecting the back plate to the angles. All welds for the sliding door design are sufficient to carry the shear loads imposed by the blast. The final Orote Point MSM door design has been shown to be capable of supporting the blast load.

2.4 PHYSICAL SECURITY

DoD Instruction 5100.76M Protection of Arms, Ammunition and Explosives requires that magazine type structures provide a minimum of 10 minutes of delay against forced entry attack. Forced entry attack refers to the level of tools that an adversary is expected to use. Military Handbook 1013/1A suggests three levels of tool threats: Low, Medium and High. The high level of threat includes hand tools requiring human strength to be effective, such as picks and pry bars; gas powered saws with steel cutting blades, such as ones used by first responders in rescue operations; and thermal tools of which the most destructive is the burn bar. The burn bar is a steel tube filled with iron rods which is burned with pressurized oxygen. The combustion of the iron produces temperatures well exceeding the melting point of A36 structural steel.

The DoD Lock Program, a division of NAVFAC ESC, has been tasked by the Physical Security Equipment Action Group (PSEAG) to developed forced entry delay technologies that can be used to protect AA&E storage facilities. By simulating an attack the DoD Lock Program noted that typical magazine door provides much less than the required 10 minutes of delay.

During the redesign of the Guam MSM, the Lock Program was consulted to incorporate increased delay technologies. That collaboration resulted in the sliding door with concrete cast over rebar at the rear of the door and a pilaster mounted lock. Analysis was conducted to ensure that the additional mass and strength of the concrete did not affect the performance of the door under blast loading. The analysis used two methods to bound the problem: (1) assuming the

concrete added only mass; (2) transforming the concrete into an equivalent amount of steel, thus increasing the moment of inertia. Each method used the SDOF calculation.

An additional blast load calculation was also performed. This blast load is defined by physical security requirements as a triangular pulse with a peak pressure of 1194 lb/in^2 and duration of 0.56 ms. The entire blast load is assumed to hit the front plate of the door in a single evenly distributed load. In all cases the door satisfied all requirements including shear strength of the stiffeners and welds. Response values are listed in Table 2.

Table 2 Response of Guam MSM door with concrete to blast loading.

Blast Loading	Method	Ductility μ	Maximum Deflection (in)	Support Rotation θ (degrees)
7-bar Blast Load	Concrete as Mass	2.226	3.342	2.175
7-bar Blast Load	Concrete increasing moment of inertia	1.947	2.818	1.834
Physical Security Blast Load	Concrete as Mass	0.926	1.385	0.902

The Lock Program Team fabricated an 8-foot by 5-foot portion of the Guam MSM door, shown in Figure 7. In November 2009, a simulated attack was performed by an Army Special Forces Group acting as a Red (attack) Team. Through that testing the door delayed the attackers for more than 10 minutes against all tools including the burn bar, thus meeting the physical security requirements. Pictures from those tests are shown in Figure 8.

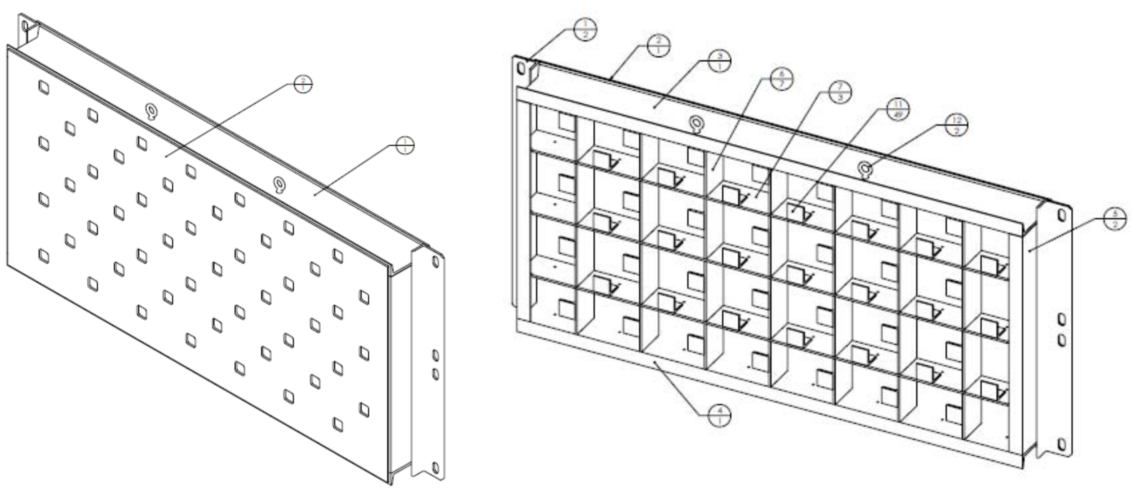

Figure 7 Guam MSM Door Test Panel Fabrication Drawings, with front plate (left) and without (right).

Figure 8 Red Team attack tests, after gas-powered saw (left), burn Bar attack (right).

3.0 ROOF PANELS

3.1 MODIFICATIONS OF MSM ROOF

Per Paragraph C5.2.1.2.4.3 of DoD 6055.09-STD (Ref. 3), the design blast load for the door of a 7-Bar earth-covered magazine (ECM) is triangular pulse with a peak pressure of 108 lb/in^2 and an impulse of $19W^{1/3}$ lb/in^2-ms. For a maximum credible event (MCE) of 500,000 lbs of net explosive weight (NEW), the design blast load is defined by a peak pressure of 108 lb/in^2 and an impulse of 1,508 lb/in^2-ms and duration of 27.93 ms.

In order to satisfy the seismic criteria in ACI 318, a concrete topping slab is included with the Orote Point MSM roof panel design. The shear strength of the roof panel was also increased by increasing the number of stirrups from the original Hill AFB design.

The Hill AFB roof panel cross-sections are type I cross-sections. Analysis performed by NAVFAC ESC showed the roof panel support rotation is less than 5 degrees. As per UFC 3-340-02, if the support rotation is between 2 and 6 degrees a type II cross-section is necessary. For a type II cross-section, the compression reinforcement equals the tension reinforcement resisting the moment that the crushed concrete is no longer capable of resisting. In order to satisfy the criteria, the compression reinforcement is increased from five #6's in the compression flange to five #9's, as seen in Figure 9. Acceptable performance of this roof panel design under blast loading was verified by two separate analysis methods: Finite Element Analysis (FEA) and the UFC 3-340-02 SDOF calculation.

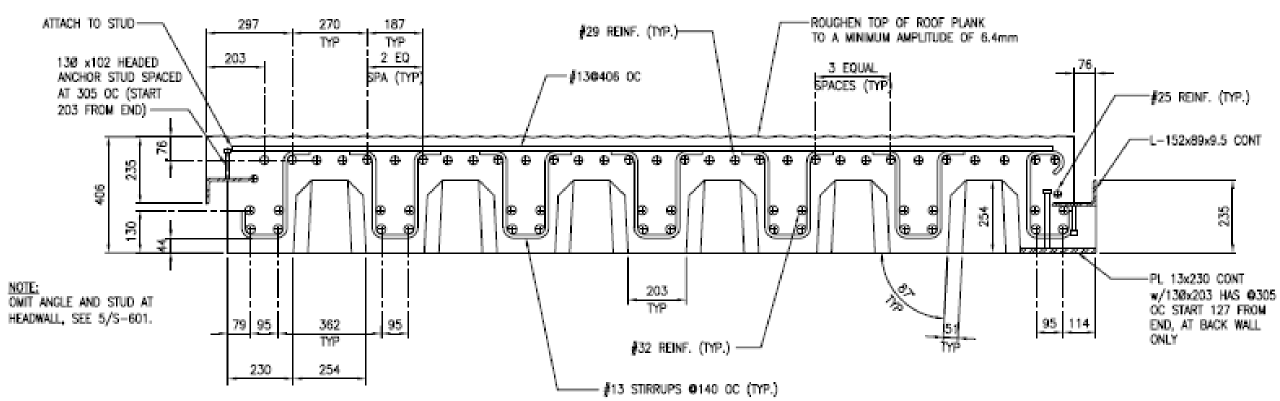

Figure 9 Roof Panel Section Final Design

3.2 FINITE ELEMENT ANALYSIS

The FEA analysis was performed using LS-DYNA v971 to simulate the roof panel response to the design blast load. The numerical analysis involves the effects of high strain rates, material non-linearity and time-dependent deformations. Simulations were run the Army Research Lab's Supercomputing Resource Center accessed through the High Performance Computing Modernization Program.

Four different roof panel configurations were analyzed. Each configuration required a separate finite element model. The four configurations are described as follows:

1. Model 1: An 18" wide "T" section with 5 #6 bars in the compression flange and 4 #10 bars at the bottom of the stem, and 2-feet of soil cover. Representative of the Hill AFB MSM.
2. Model 2: Same as Model 1 with an added 3" topping slab reinforced with #5 bars at 6-inches center-to-center. Representative of the Andersen AFB MSM.
3. Model 3: Same as Model 1 with an added sloped topping slab and #5 bars at 6-inches center-to-center spacing. The topping slab is sloped, 5.5-inches from the mid-span to 4.0-inches at the edge. Representative of the Crane, IN MSM.
4. Model 4: Same as Model 3, but the cross-section was changed from a Type I cross-section to a Type II cross-section. The five #6 bars in the compression flanged were increased to five #9's. Representative of a worst case dead load condition of the Orote Point MSM.

The FEA model for configuration #4 is shown in Figure 10. A constant stress 8-node solid element was used to represent the concrete. Hourglass control was used to minimize the effect of zero energy modes that can affect the structural response of the system. Contact between the concrete and beam elements of the steel reinforcement must be defined otherwise the elements will move through each other during computation. LS-Dyna provides several methods to accomplish this and a series of preliminary simulations were performed to determine the most appropriate.

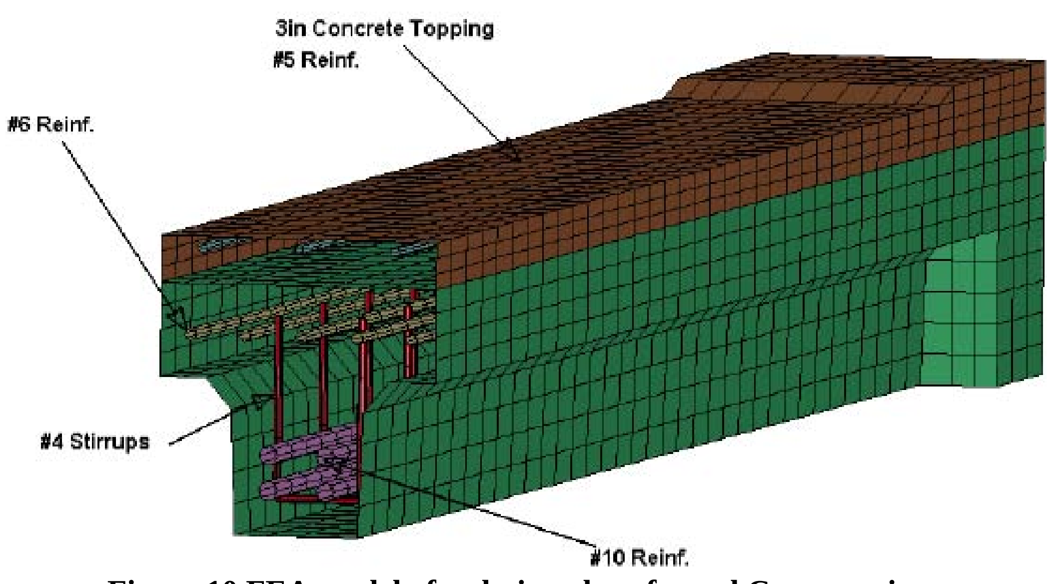

Figure 10 FEA model of redesigned roof panel Cross-section

An example of the computational result is shown in Figure 11. Each of the four configurations was shown to resist seven-bar loading with minimal deflection of less than 6 degrees for each analysis method. Results are summarized in Table 3.

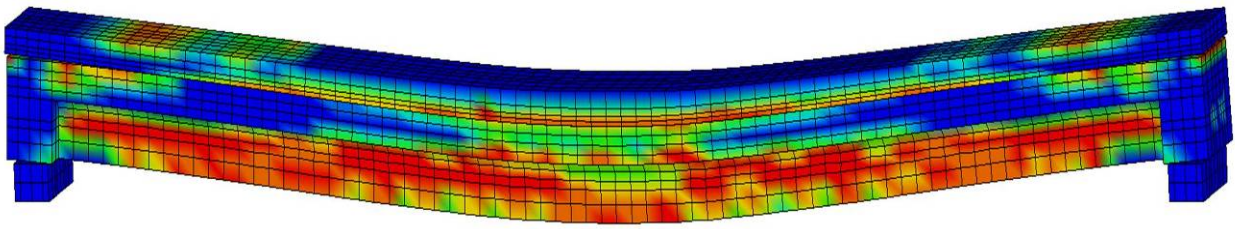

Figure 11 Beam model effective Strain contour of roof section at 61 ms under blast load.

Table 3 FEA Roof Panel Results

Model	Maximum Deflection (in)	Time at Max. Deflection (ms)	Max Support Rotation, (degrees)
Model 1: No topping and #6 compression steel	15.17	106.7	5.4
Model 2: 3-in topping and #6 compression steel	13.92	104.2	5.0
Model 3: 5.5-4 inch sloped topping and #6 compr. steel	13.08	106.4	4.7
Model 4: 5.5-4 inch sloped topping and #9 compr. steel	12.71	103.0	4.5

3.3 SDOF

The SDOF dynamic analysis is an engineering analysis that calculates the dynamic response of the roof to the blast load. The SDOF method accounts for the variation of the blast pressures as a function of time. However, the SDOF analysis does not account directly for the loss of concrete strength due in a Type I cross-section. UFC 3-340-02 assumes the compression concrete is crushed and has lost strength with support rotation greater than two degrees. For support rotations greater than 2 degrees, the tension and compression steel areas are required to be equal. The moment resistance of the roof is based on the moment created by the tension and compression reinforcement.

The calculated deflections for Type I and Type II cross-sections are presented in Table 4. The deflections of the Type I and Type II cross-sections are a maximum for the roof without the topping slab. The deflection of the roof with the 5.5-inch sloped topping slab exceeds that calculated for the 3-inch topping slab. The range of calculated deflections is less than 10 percent.

Table 4 Calculated Roof Panel Results

Cross-Section Type	Model	Dead Load (lb/in)	Dead Load (lb/in)	Available Resistance (lb/in)	Total Deflection (in)	Maximum Support rotation (degrees)
I	No Topping	43.8	43.8	280	13.99	5.33
	3-inch Top	48.5	48.5	275	12.97	4.94
	Sloped Top	52.4	52.4	271	13.17	5.02
II	No Topping	43.8	43.8	282	13.88	5.29
	3-inch Top	48.5	48.5	278	12.83	4.89
	Sloped Top	52.4	52.4	273	13.07	4.98

4.0 SIDE AND BACK WALL

4.1 MODIFICATIONS OF MSM WALLS

The connection from the side and back wall panels to the magazine floor in the Orote Point MSM design has been modified from the Hill AFB design. The connection between the pre-cast walls and the floor in the Modified STD 421-80-06 drawings does not develop the tension capacity of the vertical reinforcement. ACI 318 restricts yielding to the steel elements in connections between the floor and pre-cast concrete panels. To satisfy ACI requirements, #8 (#25) diameter dowels extend 54-inches (1372-mm) from the foundation into each wall panel.

4.2 ANALYSIS

Details of the sidewall panels are shown in Figure 12. The sidewall panel is 178.5-inches (4534-mm) tall and 12-inches (305-mm) thick.

The sidewall was analyzed as a column with a time varying axial load applied by the reaction of the roof to the blast loads using the SDOF calculation. Two methodologies were used to calculate the axial load on the sidewall and both are presented. The resistance of the roof slab with and without a concrete topping slab and the dynamic reaction of the roof with and without a concrete topping slab were applied axially to the side wall. Figure 13 is a plot of the reaction time history.

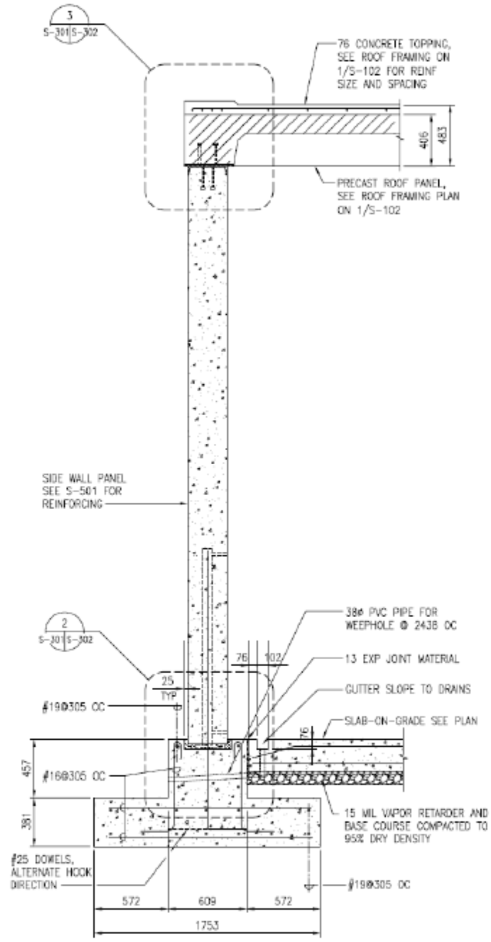

Figure 12 Side Wall Cross-section

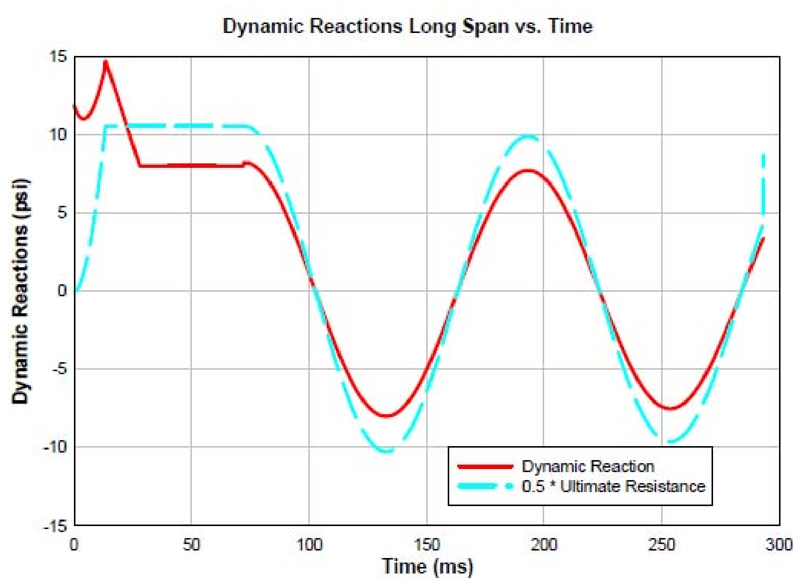

Figure 13 Sidewall Reaction force due to the roof under blast loading.

It was found that the axial compression strength of the sidewall is sufficient to survive all loading conditions. As presented in Table 5, the axial deflection and ductility indicate that the sidewall will remain elastic, and is therefore sufficient to survive the loading. The time varying responses of the roof with and without a concrete topping slab are taken from the time varying SOLVER outputs from the SDOF roof analysis.

Table 5 Side wall reaction to blast loading

		Maximum Displacement (in)	Ductility
Dynamic Reaction	No Topping Slab	0.013	0.632
	4.75" Topping Slab	0.014	0.681
Resistance	No Topping Slab	0.009	0.438
	4.75" Topping Slab	0.015	0.729

5.0 CONCLUSION

The Guam MSM began as a relatively simple site adaptation of the Hill AFB MSM. During the review several deficiencies were noted. NAVFAC ESC was tasked by NAVFAC Pacific to redesign and analyze the door, roof panel sections and wall connections to ensure compliance with explosives safety standards. During the redesign process NAVFAC ESC involved not only structural engineers but physical security specialists and magazine users to provide input to the design.

The final Guam MSM satisfies four primary planning factors:

1. Conventional structural design loads, including seismic and building codes
2. Explosives safety requirements to prevent propagation of detonation between ECMs.
3. Ordnance handling procedures define requirements to mitigate safety issues during stowing and retrieving of ordnance from the magazine.
4. Current and new physical security requirements to define the level of protection to mitigate unauthorized access to stored assets.

The redesign effort included collaboration between NAVFAC Pacific, NAVFAC ESC and Wilson Okamoto Corporation. DDESB was also kept apprised of during the design process. The final Guam MSM drawings are currently being reviewed at DDESB and approval is expected by Fall 2010.

6.0 REFERENCES

1. “Approved Protective Construction (Version 2.0)”, Technical Paper 15, DOD Explosives Safety Board, June 2004.
2. Unified Facilities Criteria 3-340-02: “Structures to Resist the Effects of Accidental Explosions,” December 2008.
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4. “Modular Storage Magazine (7620mm wide x 6096mm Min. to 2438mm Max. Length x 4470mm High)”, Final submittal (9-10-2009), NAVFAC Drawing Nos. 17049898 through 17049939.
5. Kerrigan et al. “Analysis of Modular Storage Magazine Modification,” Site Specific Report SSR-3437-SHR for Orote Point Guam. Naval Facilities Engineering Service Center, Port Hueneme, CA. December 2009.
6. “Air Force Modular Storage Magazine, Box-Type STD 421-80-06”, U.S. Army Corps of Engineers Engineering and Support Center, Huntsville, 1 October 1999, modified by Corps of Engineer Sketches S-9 through S-13, dated March 2002.
7. “Building Code Requirements for Structural Concrete (ACI 318-05)”, ACI Committee 318 Structural Building Code, American Concrete Institute, 2004.
8. “NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures (FEMA 450)”, Building Seismic Safety Council, 2003.
9. "Minimum Requirements to Validate Explosives Safety Protective Construction", DoD Explosives Safety Board, 21 October 2008.
10. “Munitions Storage Module (MSM) Part A – Main Report and Appendices A-F”, James P. Roller et al, New Mexico Engineering Research Institute, PL-TN-93-1081 Pt. A, Prepared for Phillips Laboratory Advanced Weapons and Survivability Directorate, January 1994.
11. “Munitions Storage Module (MSM) Part B – Main Report and Appendices G Test Data”, James P. Roller et al, New Mexico Engineering Research Institute, PL-TN-93-1081 Pt. B, Prepared for Phillips Laboratory Advanced Weapons and Survivability Directorate, January 1994.
12. “Munitions Storage Module Buildings”, Hill Air Force Base, Utah, Ogden Air Logistics Center, Office of Civil Engineering.
13. “Military Handbook Design Guidelines for Physical Security of Facilities,” MIL-HDBK-1013/1A, December 1993.

Naval Facilities Engineering Command
ENGINEERING SERVICE CENTER

Multidisciplinary Redesign of Hill Air Force Base Modular Storage Magazine for Orote Point, Guam

2010 DoD Explosive Safety Board Seminar

Presented by:
Paul Rossetti
Research Structural Engineer
V:805-982-4219
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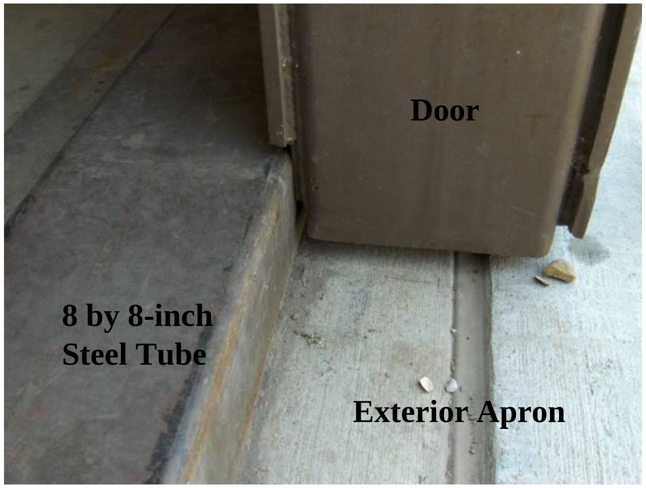
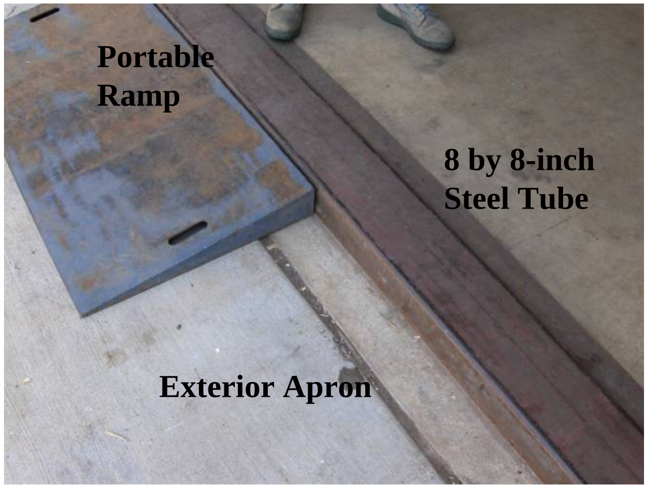
7/13/2010

An MSM under construction

Double swinging door threshold



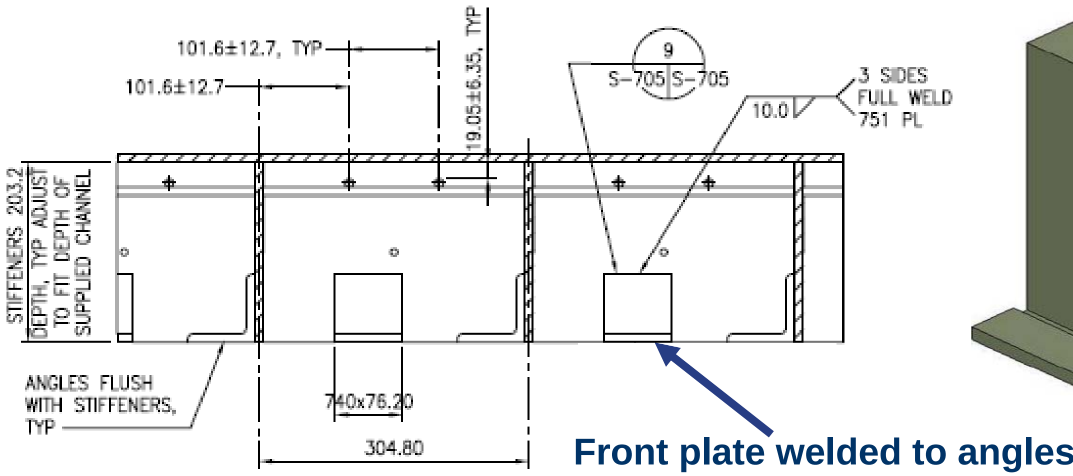


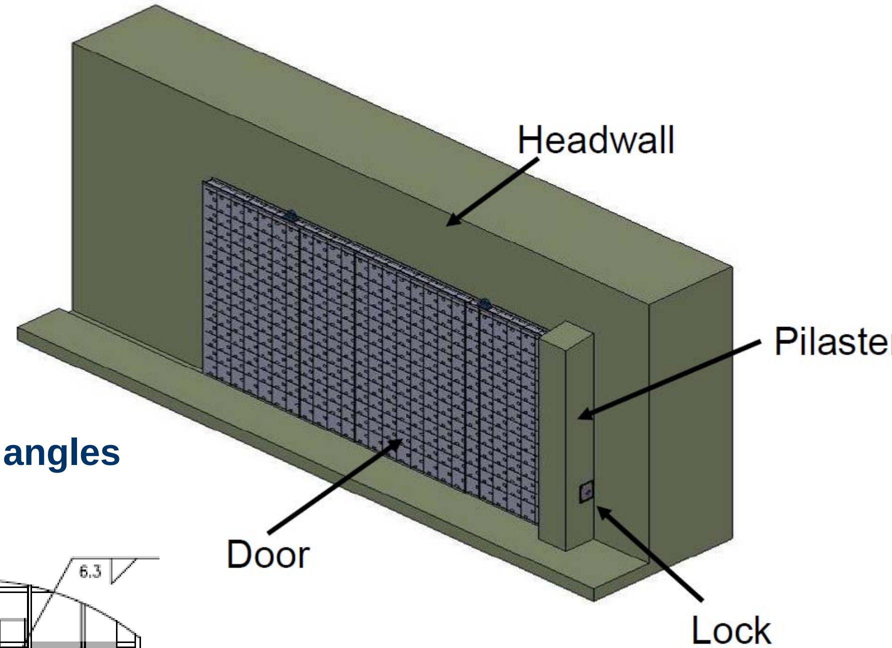
Design Issues

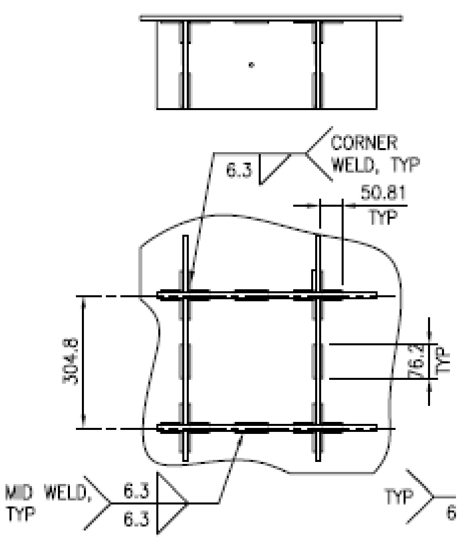
NACFAC Pacific and ESC identified four key issues:

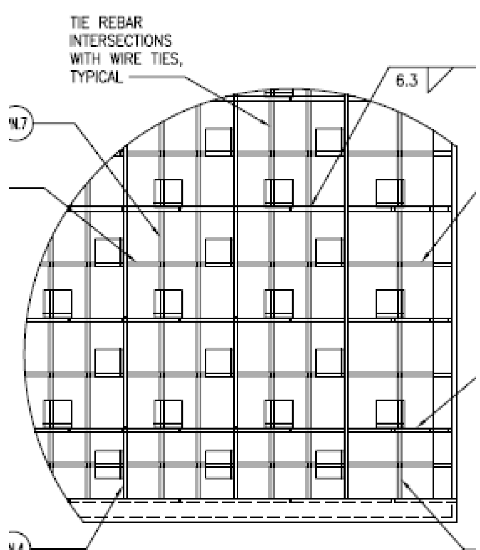
1. **Satisfying seismic design criteria in regions of high seismic activity**
2. **Eliminating safety issues during stowing and retrieving ordnance from the MSM**
3. **Satisfying physical security protection criteria**
4. **Ensuring the structural modifications satisfied explosives safety standards.**

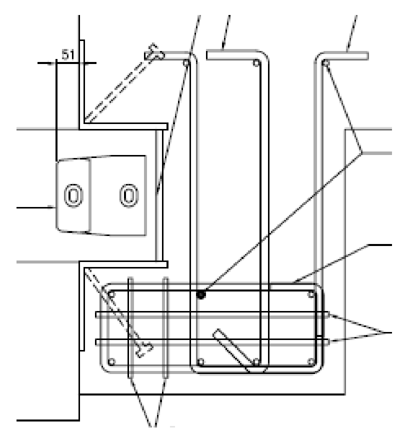
Final Door Design







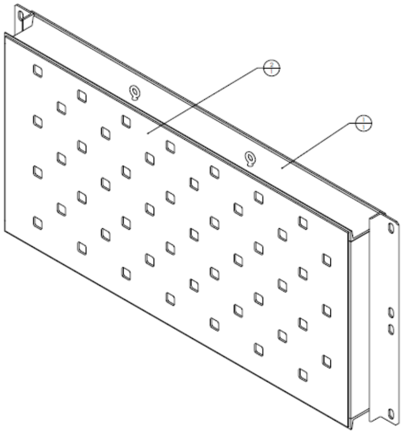


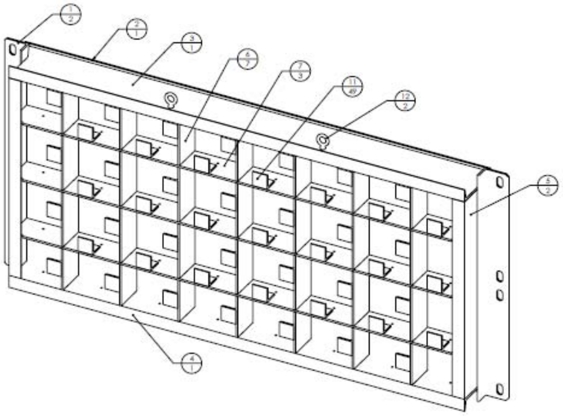


- DoDI 5100.76M requires 10 minutes of delay
- MILHDBK 1013/1A suggests high level threat tools
- DoD Lock Program with funding from the Physical Security Equipment Action Group

Gas Powered Rescue Saws

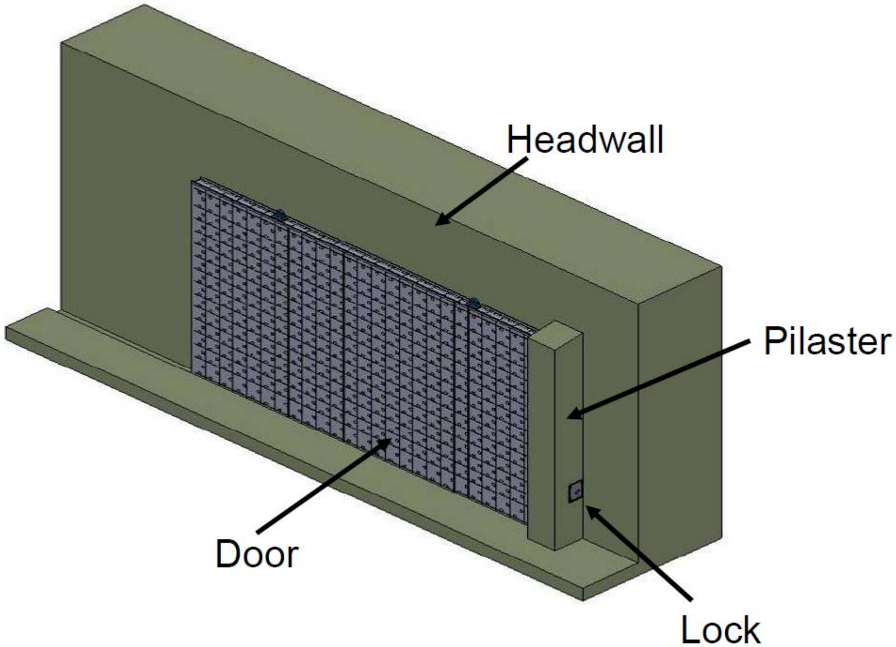
Test Panels





Burn Bar

SDOF Blast Analysis of Final Door Design



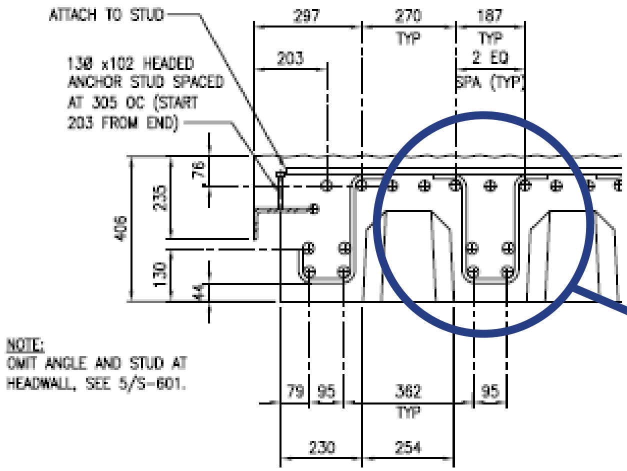
- **Two-way, Simply Supported on all four edges**

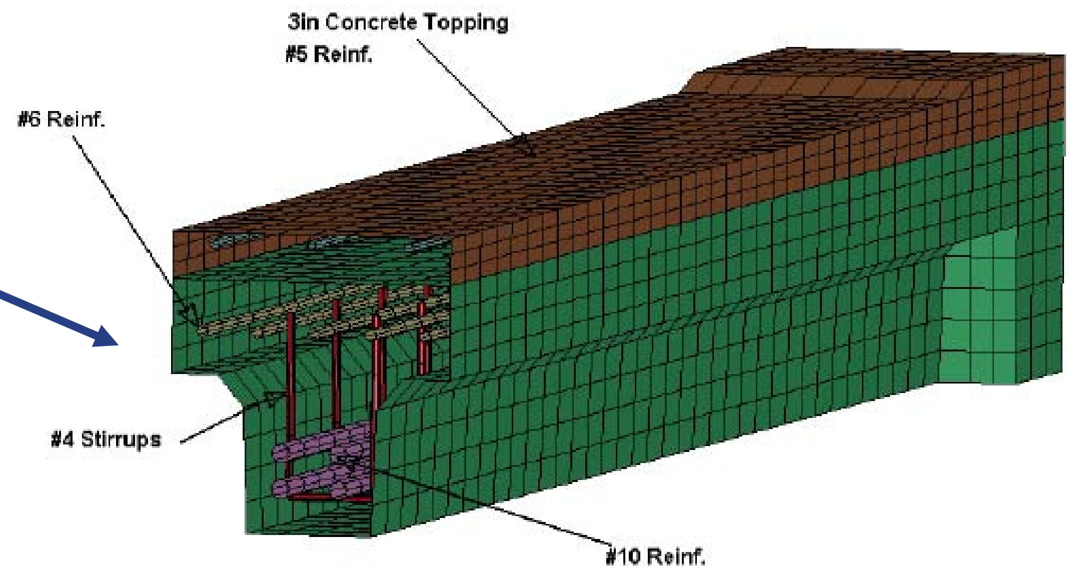
Blast Loads:

- **7-bar load 101.5 psi, 21.74ms**
- **Physical Security 1194 psi, 0.56 ms**

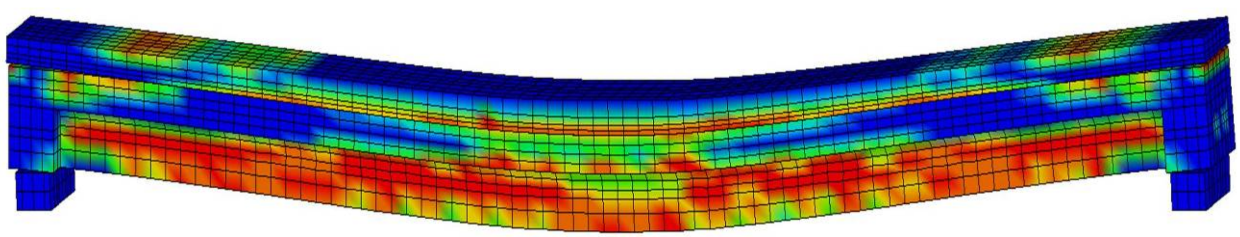
Blast Loading	Method	Ductility	Max Deflection (in)	Support Rotation (degrees)
7-bar Blast Load	Concrete as Mass	2.226	3.342	2.175
7-bar Blast Load	Concrete increasing moment of inertia	1.947	2.818	1.834
Physical Security Blast Load	Concrete as Mass	0.926	1.385	0.902

Roof Modifications and Finite Element Model





- LS-DYNA v971 at ARL's HPC
- 32 processors
- Material non-linearity, high strain rates, hourglass control

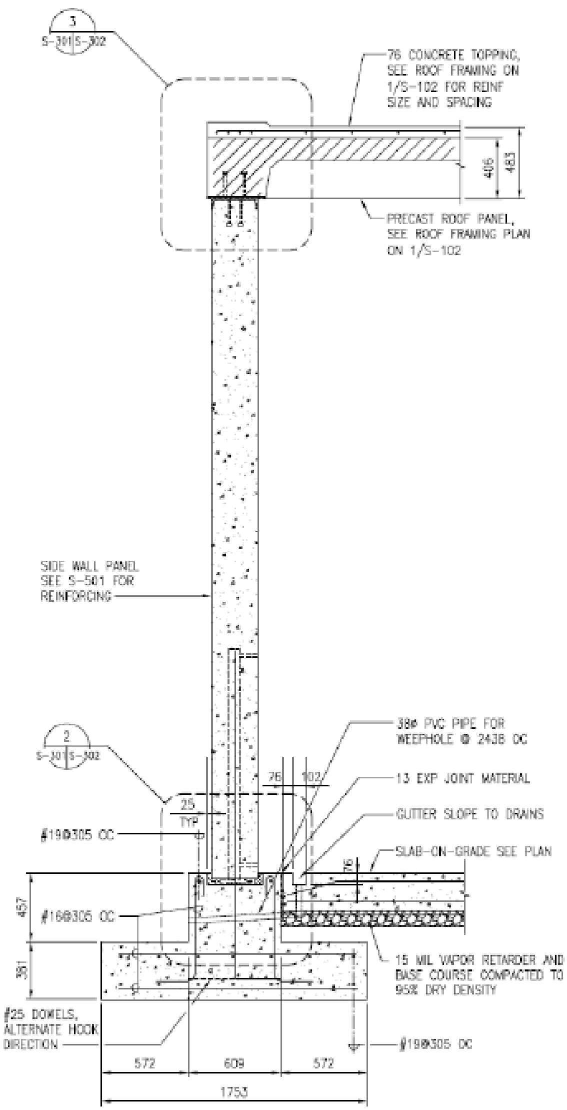


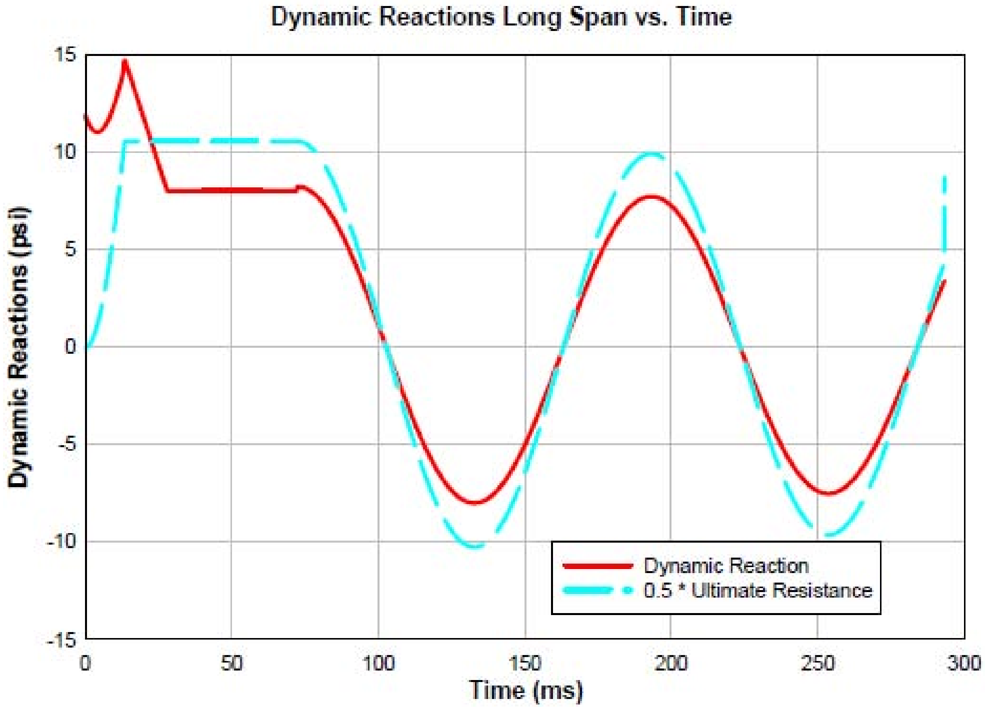
Beam model effective strain contour at 61 ms

Roof Single Degree of Freedom vs Finite Element Model

SDOF Cross-Section Type	Model	Dead Load (lb/in)	Dead Load (lb/in)	Available Resistance (lb/in)	Total Deflection (in)	Maximum Support rotation (degrees)
I	No Topping	43.8	43.8	280	13.99	5.33
	3-inch Top	48.5	48.5	275	12.97	4.94
	Sloped Top	52.4	52.4	271	13.17	5.02
II	No Topping	43.8	43.8	282	13.88	5.29
	3-inch Top	48.5	48.5	278	12.83	4.89
	Sloped Top	52.4	52.4	273	13.07	4.98

Finite Element Model	Maximum Deflection (in)	Time at Max. Deflection (ms)	Max Support Rotation, (degrees)
Model 1: No topping and #6 compression steel	15.17	106.7	5.4
Model 2: 3-in topping and #6 compression steel	13.92	104.2	5.0
Model 3: 5.5 to 4 inch sloped topping and #6 compr. steel	13.08	106.4	4.7
Model 4: 5.5 to 4 inch sloped topping and #9 compr. steel	12.71	103.0	4.5





		Maximum Displacement (in)	Ductility
Dynamic Reaction	No Topping Slab	0.013	0.632
	4.75" Topping Slab	0.014	0.681
Resistance	No Topping Slab	0.009	0.438
	4.75" Topping Slab	0.015	0.729

Conclusion

The final Guam MSM satisfies four primary planning factors:

- **Conventional structural design loads, including seismic and building codes**
- **Explosives safety requirements to prevent propagation of detonation between ECMs.**
- **Ordnance handling procedures define requirements to mitigate safety issues during stowing and retrieving of ordnance from the magazine.**
- **Current and new physical security requirements to define the level of protection to mitigate unauthorized access to stored assets.**

Final Design: NAVFAC drawings 17049898-17049939

NAVFAC ESC Report: SSR-3437-SHR

Team Effort

- Seismic Modifications: Mel Tsutahara's team at NAVFAC Pacific

NAVFAC ESC Team:

- **Team Lead: Kevin Hager**
- **Physical Security Modifications: Paul Rossetti**
- **Roof Finite Element: Youssef Ibrahim, Cecilia Booker**
- **SDOF of Roof, door and Walls: Catherine Kerrigan**